

# SOLAR AND SOLAR-TYPE STARS ATMOSPHERE'S ACTIVITY AT 11-YEAR AND QUASI-BIENNIAL TIME SCALES

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**Abstract.** We studied new simultaneous observations of the flux variations of the photospheric and chromospheric emissions of 33 solar-type stars and Sun during the HK-project that were conducted over the past 20 years. In addition to the known cyclic chromospheric emission variations of stars at the 11-year time scale, which were discovered at the Mount Wilson Observatory, we found a recurrences that are similar to the quasi-biennial variations of solar radiation. The results of calculations of the radiation fluxes variations periods of stars at the quasi-biennial scale are given.

**KEYWORDS:** Sun, solar-type stars, 11-year and quasi-biennial cycles of activity

## Introduction

The photospheric observations of stars with active atmospheres that have been conducted regularly in the optical range since the middle of the 20th century found low-amplitude variability in some of them, which is mainly caused by the presence of dark spots on the surfaces of stars, such as sunspots. Later, at the Mount Wilson Observatory an extensive program of simultaneous observations of more than a hundred stars with solar-type chromospheric activity was launched. These observations (the HK-project) have been performed for over 40 years, from 1965 to the present time [1,2].

In the framework of the HK-project the relationship of the flux in the centers of the H and K Ca II emission lines (396.8 and 393.4 nm respectively) to the fluxes in the nearby continuum (400.1 and 390.1 nm respectively) is determined. This relationship is called the  $S_{CaII}$  index by authors of the observations. It's known that the  $S_{CaII}$  index is a good indicator of the chromospheric activity of the Sun and stars.

Here, we use new data of simultaneous observations of photospheric and chromospheric fluxes variations of the Sun and 33 solar-type stars, obtained during the last 20 years at the Lowell (photometric observations) and Smithsonian observatories (observations of the H and K Ca II emission lines) of Stanford University during the HK-project [1]. We use these data for the

calculation of the cyclic activity periods of the fluxes variations of the Sun and stars.

In this work we confirm the existence of cyclic variations of the radiation in the quasi-biennial time scale for the majority of the studied solar-type stars, as well as to determine the periods of these variations.

### **1. Long-term changes in the activity of solar-type stars**

Solar and stellar activity is a combination of regular manifestation of characteristic entities in the atmosphere, which are associated with the release of large amounts of energy, whose frequency and intensity change cyclically.

In this paper we consider the cyclic variation of Sun's and star's atmospheres fluxes at 11-year and quasi-biennial time scales. Note that the duration of the so-called 11-year solar activity varies from 8 to 15 years according to many years of observations. This includes regular observations of solar activity during the last one and half centuries, as well as circumstantial evidence, including radionuclide and other types of evidence on timescales of 1000 years. The main indices of solar activity that characterize the study of the full solar disk radiation are the Wolf numbers (the longest series of observations) and the radio flux at 10,7 cm wavelength ( $F_{10,7}$ ). Extra-earth atmospheric observations in the ultraviolet and X-ray ranges of the whole solar disk and of individual active regions (characterizing the activity at different altitudes of the atmosphere) were started in the 1960s. Unfortunately, these observations, which are important for understanding the nature of the solar activity, are less regular compared with ground-based observations of Wolf numbers and  $F_{10,7}$ . They depend on the operation time of the corresponding instruments in the circumterrestrial orbit. However, according to numerous studies of solar activity indices, in particular, flows in individual lines in short-wave region, all of them correlate well with Wolf numbers and with a more objective index of activity  $F_{10,7}$ .

Observations of stars give us information only about the magnitude of radiation fluxes from the full disk. By choosing stars that are closest in their characteristics to the Sun, we transfer knowledge about the physical processes in the solar atmosphere to these stars, which makes it possible to successfully interpret their radiation flux variations. Naturally, the Sun and every single solar-like stars differ in their mass, average density, surface temperature, the total area of sunspots, their contrast, the dependence of the temperature of the photosphere and chromosphere on the different altitudes, sizes and contrast of faculae, and many other parameters. Analysis of the observations of radiation flux variations of the Sun and solar-type stars sug-

gests that the structures of the atmospheres of most of these stars are similar to that of the Sun. The parameters that differ depend on the mass of a star, its spectral class, age, chemical composition, and so on. Such an approach makes it possible to successfully interpret the observations of variations of radiation fluxes of many solar-type stars, considering the stars as analogs of the Sun, particularly at different stages of evolution.

For the HK-project stars, periods of 11-year cyclic activity (according to observations during 40 years [1,2]) change a little for one stars and range from 7 to 20 years for various stars with established activity (about 30% of the total number of stars studied in this project).

By analogy with the detailed study of formations on the Sun, the formations on the disk that are responsible for the atmospheric activity without flares of solar-type stars include spots and faculae in the photosphere, flocculi in the chromosphere, and prominences and coronal mass ejections in the corona. Areas where all these phenomena are observed together are known as centers of activity or active regions.

Thus, when analyzing radiation fluxes in the H and K Ca II lines (which are sensitive to chromospheric activity) and flows from the entire disc in broadband filters of the photospheric ubvy-system close to standard UBV-system [1,2] for the Sun and the stars it's necessary to take into account the contribution from the existing disk's active regions. Active regions are formed where strong magnetic fields emerge from underneath the photosphere. In other words, the different manifestations of the activities of the atmospheres of the Sun and stars are the result of the magnetic fields evolution. This involves both global and local magnetic fields. Their interaction with the magnetized substance in subphotospheric layers of stars involved in convective motion is also important. By their size and lifetime active regions vary greatly. They can be observed from several hours to several mouths.

It was shown that from all solar-type stars that belong to stars of spectral classes F,G and K of the main sequence on the Hertzsprung-Russell diagram, a regular cyclicity of chromospheric activity of the solar type is more common for stars of the late spectral classes G and K with sufficiently formed subphotospheric convective zones [3]. These stars rotate relatively slow on their axes (the rotation period is about 25 - 45 days, in contrast to 3 -10 days for stars with thin subphotospheric convective zones).

The Sun, a star of G2 class, rotates with the period of 25 days. The rotation period  $T_{rot}$  around their axes for a sample of studied stars, their spectral classes, the quality of their 11-year cyclicity, and values of respective periods  $T_{11}^{HK}$ , according to prior calculations made in [2] are given in table.

We mentioned that all the interpretations of variations in radiations fluxes of stars are based on the assumption that solar-type stars (and it is confirmed

by all observations) have the same active regions, which evolve in one or more periods of rotation around their axes by the same laws that operate on the Sun.

In addition, the time dependence of variations of the radiation flux from the Sun and stars, which takes into account the rotational modulation (the time scale is about 1 month), on large scales (of approximately several years) takes the form of a sine wave with a period of  $T_{11}$  corresponding to the 11-year scale of cyclic activity.

Based on the example of changes in radiation fluxes in the H and K Ca II lines for the Sun and stars we see [1] that the amplitude of the sine wave varies slightly from cycle to cycle. The change in the amplitude of the light curves of stars for each cycle depends on the contribution of preexisting and already decayed active regions in the so-called background radiation in chromospheric lines. An additional contribution to the amplitude increased in chromospheric lines is made by higher brightness at the peak of a cycle from the so-called chromospheric network.

For studies of the Sun, one of the most important problems is to forecast the cyclical activity, which affects a number of terrestrial processes. We also consider that the stars of the HK-project with stable cyclical activity in the 11-year time scale, established after 40 years of continuous observations, are so similar in their cyclical activity to the Sun, that for the prediction of the radiation fluxes from these stars methods that are used in the practice of solar forecasting are quite applicable [4,5].

This once again confirms the similarity of the various manifestations in the evolution of the atmospheric activity of the Sun and solar-type stars.

## **2. The results of calculations of the variation periods of the star's fluxes**

Recently, in some works the variations of the radiation from the Sun and stars have been investigated on different time scales with the help of modern approaches (the application of wavelet analysis to the observational data). In particular, in [6] the recurrence of solar activity was analyzed based on observations of sunspots (1750 - 2000) and solar radio-range radiation (1950 - 2000). A distinct cyclicity of the solar activity was revealed with periods of 10 - 11 years and 2 - 3 years. The authors studied the variations of the radiation of solar-type star EI Eri. The period of cyclicity of brightness variations of the star has been determined; it is 2.7 years [6], which is consistent with our computational results for 33 stars and confirms the widespread phenomenon of quasi-biennial variations of solar-type stars.

Table

No	Star	Sp.class	$T_{rot}$ (day)	Cyclicity,[1]	$T_{11}^{HK}$ (yr)	$T_{11}$ (yr)	$T_{11}$ (yr)
1	Sun	G2-G4	25	EXCELL	10.0	10.7	2.7
2	HD1835	G 2.5	8	FAIR	9.1	9.5	3.2
3	HD10476	K1	35	EXCELL	9.6	10.0	2.8
4	HD13421	G0	17	UNACT	-	10.0	-
5	HD18256	F6	3	FAIR	6.8	6.7	3.2
6	HD25998	F7	2	UNACT	-	7.1	-
7	HD35296	F8	4	UNACT	-	10.8	-
8	HD39587	G0	5	UNACT	-	10.0	-
9	HD75332	F7	4	UNACT	-	9	2.4
10	HD76572	F6	4	POOR	7.1	8.5	-
11	HD81809	G2	41	EXCELL	8.2	8.5	2.0
12	HD82885	G8	18	FAIR	7.9	8.6	-
13	HD103095	G8	31	EXCELL	7.3	8.0	-
14	HD114710	F9.5	12	GOOD	16.6	16	2.0
15	HD115383	G0	3	UNACT	-	10.3	3.5
16	HD115104	K1	18	GOOD	12.4	11.8	2.7
17	HD120136	F7	4	POOR	11.6	-	3.3
18	HD124570	F6	26	UNACT	-	-	2.7
19	HD129333	G0	3	UNACT	-	9.0	3.2
20	HD131156	G2	6	UNACT	-	8.5	2.8
21	HD143761	G0	17	UNACT	-	-	-
22	HD149661	K2	21	GOOD	17.4	14.5	3.5
23	HD152391	G7	11	EXCELL	10.7	10.8	2.8
24	HD157856	F6	4	FAIR	-	12.9	2.6
25	HD158614	G9	34	UNACT	-	12.0	2.6
26	HD160346	K3	37	EXCELL	7.0	8.1	2.3
27	HD161239	G2	29	FAIR	5.7	6.5	-
28	HD182572	G8	41	UNACT	-	10.5	3.1
29	HD185144	K0	27	UNACT	-	6,5	2.6
30	HD190007	K4	29	FAIR	10.0	11.0	2.5
31	HD201091	K5	35	EXCELL	12.0	13.7	2.8
32	HD201092	K7	38	GOOD	12.4	11.7	2.5
33	HD203387	G8	-	UNACT	-	-	2.6
34	HD216385	F7	7	POOR	-	7.0	2.4

In a recent paper devoted to the quasi-biennial variations (QBV) of solar radiation fluxes [7] the importance of the QBV problem studying was em-

phasized. It turned out that QBV modulations of total flux of solar radiation are closely related to various quasi-biennial variations QBV processes on the Earth, in particular with the QBV of the Earth's rotation speed, the QBV of the velocity of the stratospheric wind, etc. The existence of activity of stars on the quasi-biennial time scale emphasized the fact that solar activity is a phenomenon that is characteristic of the main sequence stars of late spectral classes with developed subphotospheric convective zones. The correct theory of the subphotospheric convection for Sun and solar-like stars not having been made for the present time [8].

The results of our calculations are shown in the table. We used observations of radiation fluxes in chromospheric lines (the  $S_{CaII}$  index). We have scanned 33 stars and the Sun's  $S_{CaII}$  index light curves using [1] observational data. Then the method of fast Fourier transform was applied to these scanned data. So we determined the periods of 11-year cycles (the  $T_{11}$ ) and the quasi-biennial cyclicity (the  $T_2$  period) of chromospheric activity for the Sun and 33 stars.

A dash in columns with  $T_{11}$  and  $T_2$  means that we have not identified the periodicity at a given time scale. The table also presents results of the determination of 11-year periods of stars  $T_{11}^{HK}$ , determined for the first time by HK-project participants and the quality of the cyclicity of the  $S_{CaII}$  index variations [1]. One can see a good agreement of these results with our calculations results of the  $T_{11}$  periods.

Note that in some stars with well-determined 11-cyclicity (quality of the cyclicity is EXCELL or GOOD, as mentioned in table) variations of fluxes are bimodal near the maximums of the cycle, in a similar manner to the data for the Sun (according to sun's and star's observations from [1]).

According to the results of the table, 75% of the stars of the sample [1,2] have well-pronounced quasi-biennial fluxes variations, similar to variation of solar radiation at the same time scale. The periods of quasi-biennial star's cycles (values  $T_2$ ) differ in the range from 2.2 to 3.5.

The preliminary analysis of the QBV in the stars showed that the duration of this cycle is not constant during one 11-year cycle, as in the case of QBV of Sun's fluxes. The duration of the QBV of Sun's fluxes varies on average from 39 months at the beginning of the 11-year cycle to 25 months at the end of it [9].

We compared the data on the photospheric and the chromospheric emission of HK-project stars according to [1] observations. For stars with low level of chromospheric activity (Group I, including the Sun) the correlation is direct. The photospheric emission is correlated with the  $S_{CaII}$  index on time scales of 3 - 20 years. The other stars (for Group II) are characterized by inversely directed variations in the photospheric continuum and chro-

mospheric lines. The correlation coefficients between the photospheric and chromospheric emission for some stars are high (up to 0,7), differing by the sign for Groups I and II. One can see that stars both with the correlation and anticorrelation of activity indexes corresponding to different atmospheric levels have the QBV of radiations fluxes.

## Conclusions

A statistical analysis was conducted of observations of the Sun and 33 stars of the HK-project using the fast Fourier transform. From the spectral analysis of the corresponding changes of radiation fluxes in Ca II lines we defined the periods of  $T_{11}$  11-year cyclicity and also revealed a recurrence that similar to the quasi-biennial solar cyclicity and determined the  $T_2$  periods.

The table shows that the periods of cycles on the 11-year scale  $T_{11}^{HK}$  identified by observers at Mount Wilson during the primary treatment of the HK-project observations [2] agree well with our  $T_{11}$  periods.

It can be concluded that the QBV phenomenon of radiation fluxes is common among solar-type stars. According to our estimates, this QBV phenomenon is observed in stars about twice as often as well-determined cyclic activity in the 11-year scale. The periods of QBV cycles  $T_2$  for the studied sampling of stars, according to our calculations, range from 2.2 to 3.5 years.

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